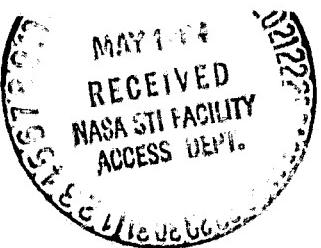


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NASA CASE NO. MSC-20,543-1

PRINT FIG. 1

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AWARDS ABSTRACT

NASA Case No. MSC-20543

TANKER ORBIT TRANSFER VEHICLE AND METHOD

The instant invention is directed to a multi-stage orbit transfer vehicle and mission profile technique designed to increase fuel efficiency and payload delivery capability to a desired orbit. The invention is particularly suited to deployment of payloads in orbits greater than the present capabilities of the Shuttle, e.g., geosynchronous orbit.

A first stage 12 of the vehicle 10 performs a burn from a lower earth orbit (LEO) 38 (Fig. 2), which might represent the orbit of the Shuttle Orbiter, to an intermediate, or parking orbit 42. The second stage 14 then undocks and performs its burn to reach the desired greater earth orbit (GEO) 40. After completing its mission, the second stage returns to the parking orbit, the stages dock at connector 16, and the first stage provides the fuel required to return both stages to LEO. Because that portion of the fuel required to return the second stage to LEO is left in the parking orbit with the first stage, the total amount of fuel required to perform the GEO mission is decreased and the payload can be increased accordingly. Among variations contemplated are an engineless first stage which stores fuel and transfers sufficient fuel to the second stage's engines in the parking orbit to achieve the round trip from parking orbit to GEO.

Novelty appears to reside in the specific technique for interorbit transport which provides for more efficient use of fuel and greater payload capabilities to GEO, together with reusability of all stages of the system.

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TANKER ORBIT TRANSFER VEHICLE AND METHOD

Origin

The invention described herein was made by an employee of the United States Government and may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

Background of the Invention

1. Field of the Invention

The present invention is related to techniques for manipulating orbiting spacecraft. More particularly, the present invention pertains to methods and apparatus for providing transportation between orbits of different radii, or of different mean radii. It will be appreciated that the present invention is generally applicable to transportation between orbits other than earth orbits, such as lunar orbits or orbits about other planets. However, for purposes of simplicity rather than limitation, the description of the present invention is provided herein generally in terms of earth orbits.

2. Discussion of Prior Art

Exploration and research in space have developed to the stage of commercial exploitation, particularly in the field of communication satellites, for example. A large number of satellites, performing a variety of tasks, is maintained in geosynchronous orbit, that is, in circular orbit stationary relative to the surface of the earth, approximately 20,000 nm in radius. The space shuttle provides a mechanism for placing additional satellites in orbit, and retrieving orbiting satellites for repair or replacement. However, inherent limitations of the space shuttle as currently available prevent the shuttle from operating in an orbit greater than approximately 160 nm altitude. Consequently, satellites are currently launched into orbit from the shuttle, relying, for example, on engines carried by the satellites to achieve the appropriate geosynchronous orbit of greater radius.

Additionally, the space shuttles currently launched from Florida are placed in earth orbit in a plane at an angle of

inclination of approximately 28.5° relative to the equatorial plane. A geosynchronous orbit, of a satellite for example, must be in the equatorial plane.

Interorbit transportation can also be expected to be required after the advent of a space station. Orbit transfers of payloads may still take place to properly position satellites or other spacecraft in geosynchronous orbit, or to retrieve such craft back to a space station.

It is advantageous and desirable to obtain reliable and efficient means for effecting orbit transfers of payloads. Several types of orbit transfer vehicles are currently available, or have been proposed. For purposes of discussion, these vehicles are considered herein in the context of transportation between a lower earth orbit (LEO) of say a space shuttle, and a greater earth orbit (GEO) in the equatorial plane wherein a spacecraft may be in geosynchronous orbit.

The simplest type of orbit transfer vehicle is a single stage craft with rocket engines. It will be appreciated that an engine burn is required each time a craft changes path, such as entering or leaving a particular orbit. It will also be appreciated that such a path change can include a change of the plane of a craft's orbit as well as the orbit shape and size. Four burns of the rocket engines are thus required to complete a roundtrip mission of the single stage craft. The first burn propels the single stage vehicle out of the generally circular LEO into an elliptical orbit whose perigee and apogee are tangential to the LEO and GEO, respectively (known as a Hohmann transfer orbit). A second burn at the transfer orbit apogee places the vehicle in GEO. Upon completion of the mission at GEO, a third burn propels the vehicle into the same or another Hohmann transfer orbit, whereupon, at perigee, the fourth burn returns the vehicle to LEO for rendezvous with the shuttle, for example. The orbit transfer vehicle is thus reusable. Variation in the orbit plane inclinations may be effected with each of the four burns, for example. Since the single stage craft carries all of its fuel for the entire mission, the operation of the craft for such interorbit transport is inefficient.

A two-stage orbit transfer vehicle has been considered

wherein each of the stages includes an engine assembly and fuel-carrying capacity. The first stage engines are burned to propel the linked stages out of LEO into an intermediate orbit, whereupon the stages are separated and the first stage engines
5 operated to bring that stage back to LEO. The second stage engines are burned to propel the second stage from the intermediate orbit to GEO. The second stage then propels itself back to LEO in the general fashion of a single stage vehicle as described above. The two stages must rendezvous with the
10 shuttle in LEO, and can each be used again. Such a two-stage vehicle operation is inefficient because all of the fuel necessary to return the second stage to LEO must be transported therewith to GEO.

A variation of the two-stage orbit transfer vehicle is the
15 one and one-half stage, or drop tank, vehicle. In this case, the first stage is merely a large tank that feeds fuel to the rocket engines of the second stage. Such fuel is consumed to propel the two linked stages out of LEO. Thereafter, the stages are separated, and the tank is either left as orbital debris or
20 re-enters the earth's atmosphere and burns up. The second stage goes on to GEO, from where it returns to LEO generally as a single stage vehicle. The drop tank vehicle has a greater payload capability than the vehicle with two reusable stages.

Another two-stage orbital transfer vehicle version includes an aero-brake device carried by the first stage, for example, which is also equipped with an engine. After the two stages separate in the intermediate orbit, the second stage goes on to GEO while the first stage operates its engines to lower its altitude whereupon the aero-braking device may interact with the upper atmosphere to further slow the first stage to LEO. After the second stage leaves GEO, it may also employ an aero-brake to reduce its velocity in the upper atmosphere to return to LEO. Aero-braking would reduce the amount of velocity change that must be effected by fuel consumption, but would
30 require the use of aero-braking heat shields and controls necessary to fly through the outer atmosphere.

A variation of the two-stage orbit transfer vehicle with aero-braking employs a drop tank as the first stage for further

fuel savings and payload increase.

The present invention provides a technique for interorbit transport that permits greater payloads to be carried to GEO and/or returned therefrom with more efficient use of fuel as well as reuse of all stages of the orbit transfer vehicle system.

Summary of the Invention

The present invention provides method and apparatus, including a two-stage vehicle referred to as a tanker orbit transfer vehicle, wherein a roundtrip mission between LEO and GEO may be completed with both stages returned to LEO, and wherein the second stage which is temporarily placed in GEO is not required to transport to GEO, the full fuel allotment consumed to return to LEO.

An orbit transfer vehicle according to the present invention includes a first, or tanker, stage having a first container for containing propellant fuel, and a second, or core, stage having a second container for containing propellant fuel and also equipped with a second stage engine system. The spacecraft further includes apparatus for releasably connecting the two stages. The mutually connected two stages may be placed in a first orbit, and propelled therefrom into a generally elliptical parking orbit. In the parking orbit, the two stages may be separated, and the second stage engine system operated to propel the second stage into a generally elliptical transfer orbit whose apogee is approximately the same as the radius of a second orbit which may be generally concentric with the first orbit but of greater mean radius. The second stage engine system may again be operated to propel the second stage into the second orbit. Further operation of the second stage engine system may propel the second stage into a generally elliptical transfer return orbit whose apogee is approximately equal to the mean radius of the second orbit. The second stage engine is operated at the perigee of the transfer orbit to put the second stage into the parking orbit. The first and second stages may thereafter rendezvous and link together, and then be propelled back into the first orbit. While the second stage makes its journey to and from the second orbit, the first stage

remains in the parking orbit, where it may be located for the subsequent rendezvous with the second stage. The various orbits may exhibit different angles of inclination, and operation of the spacecraft engines to effect transfer from one orbit 5 to the next may appropriately alter the orientation of the spacecraft's orbit as well as shape and size of the orbit.

A spacecraft according to the present invention may also include fuel transfer apparatus for conveying fuel from the first stage to the second stage, for example, for use in 10 operation of the second stage engine system when the two stages are mutually linked. Additionally, or in the alternative, a spacecraft according to the present invention may include an engine system as part of the first stage. The first stage engine system may be utilized, for example, in propelling the 15 linked stages from the first orbit into the parking orbit, and may also be used for propelling the linked stages from a parking orbit back into the first orbit. Further, a "rescue mission" may be effected with a spacecraft according to the present invention if, for example, the second stage engine system 20 should fail while the second stage is in the second orbit. In such case, the first stage engine system may be utilized to propel the first stage into the greater orbit where rendezvous with the second stage may be carried out. Thereafter, the first stage engine system may be utilized to return the first stage, 25 or the linked stages, to the first orbit, consuming propellant fuel carried by the first stage and/or originally by the second stage.

A spacecraft according to the present invention may also be equipped with an aero-brake system. For example, the first 30 stage may be equipped with an aero-brake heat shield and appropriate controls for operation of the heat shield and manipulation of the spacecraft through an atmosphere. The aero-brake system may be utilized, for example, in manipulating the linked stages between the parking orbit and the first orbit.

The second stage of a spacecraft according to the present invention, which stage is intended to proceed to the greater radius orbit and return, may be equipped with a capsule facility 35 to accommodate a crew and/or payload. In general, the first,

or tanker, stage carries fuel for consumption while the two stages are linked.

Brief Description of the Drawings

Fig. 1 is a side elevation, at least partly schematic, of
5 a tanker orbit transfer vehicle according to the present invention;

Fig. 2 is a schematic representation of various orbits that might be achieved utilizing a spacecraft according to the present invention;

10 Fig. 3 is a view similar to Fig. 2, but particularly applicable to a spacecraft according to the present invention employing an engine system on the second stage only;

15 Fig. 4 is a view similar to Fig. 1, but illustrating an embodiment of a spacecraft according to the present invention employing an aero-brake system;

Fig. 5 is a view similar to Figs. 2 and 3, but particularly applicable to a spacecraft according to the present invention equipped with an aero-brake system as illustrated in Fig. 4; and

20 Fig. 6 is a view similar to Figs. 2, 3 and 5, but illustrating the shifting of orbits due to perturbations.

Description of Preferred Embodiments

Fig. 1 illustrates generally at 10 one version of a tanker orbit transfer vehicle according to the present invention. The
25 spacecraft 10 includes a first stage 12 coupled to a second stage 14 by a connector assembly 16. The connector assembly 16 may be of any appropriate construction, designed to selectively uncouple at the location indicated by the arrow 18, for example, and to appropriately re-engage upon subsequent rendezvous and
30 docking of the first and second stages 12 and 14, respectively.

For purposes of illustration rather than limitation, the first and second stages 12 and 14, respectively, are shown herein as modifications of the Centaur "F" upperstages of the Atlas and Titan rocket systems. The Centaur "F" stage is used
35 for purposes of illustration since such craft are generally currently available, and because advanced versions of the Centaur "F" and "G" versions have been currently chosen for production as orbital transfer vehicles in general.

Thus, as illustrated, the first stage 12 includes a propellant fuel compartment 20, a first stage engine assembly 22, and a fuel transfer fixture 24. Similarly, the second stage 14 includes a propellant fuel container 26, a second stage engine assembly 28, and a fuel transfer fixture 30. Since the second stage 14 is intended to travel to GEO to carry out the mission of the tanker orbit transfer vehicle, a payload capsule 32 is included in the second stage. The capsule 32 may be equipped to transport and sustain crew members and/or payload in general. An optional fuel transfer line such as indicated at 34 extends from the fuel transfer fixture 24 of the first stage 12, and is equipped to be selectively connected to the fuel transfer fixture 30 of the second stage 14 when the two stages are linked by the connector assembly 16. In this way, propellant fuel may be transferred between the two stages whereby fuel from one stage may be used to operate the engine assembly of the other stage. The connection of the fuel transfer line 34 may be automatic on linking by the connector assembly 16, or may be effected by a crew member operating outside the craft 10.

In general, the tanker orbit transfer vehicle according to the present invention may be constructed and operated with but one engine assembly, and that as part of the second stage for propulsion thereof to and from GEO. In such case, for example, the first stage may be joined to the second stage by a connector assembly variation which positions the first stage toward the front of the second stage, and utilizes a fuel transfer line such as 34 to convey propellant fuel from the first stage to the second stage for operation of the second stage engine assembly when the two stages are so linked. The first stage thus serves generally as a fuel tank to be deposited in a parking orbit while the second stage travels to GEO, and to be retrieved from the parking orbit upon return of the second stage.

It will be appreciated that additional modifications of the Centaur type rockets could be made for their use in a tanker orbit transfer vehicle according to the present invention. For example, with cryogenic fuels, proper insulation could be provided to reduce boil-off of the propellant fuel. Additional shielding could be provided to protect the spacecraft against

meteor impact during long missions. Fuel cells could be added, for example, to meet the energy requirements of operation and manipulation of the vehicle throughout its mission. Additional such modifications, possibly including avionic changes, may 5 also be employed. All such improvements are of types employed elsewhere in the space program, or are at least within current technology.

In the vehicle configuration shown in Fig. 1, both stages are of the same size, that is, both stages have the same fuel 10 container capacity. As a further modification of the tanker transfer orbit vehicle according to the present invention, one of the stages may be constructed with an increased fuel capacity compared to that of the other stage. For example, where only 15 the second stage includes an engine system, the first stage serves as a fuel storage facility and may be considerably larger than the second stage. In that case, the second stage engine burns to take the linked stages out of and back to LEO may be carried out utilizing fuel stored in the first stage. The second stage need carry only as much fuel as would be required 20 for that portion of the craft to go from the parking orbit to GEO and back to the parking orbit. It will be appreciated, however, that the amount of velocity change to be effected at the various burns varies with the mass of the craft portions undergoing the orbit changes. Additionally, the sizes of the 25 parking and transfer orbits compared to the generally circular LEO and GEO will also vary with the variation in stage mass.

An orbit pattern which might be achieved utilizing a tanker orbit transfer vehicle with engines on both stages and with equal fuel capacity for both stages, as illustrated in Fig. 30 1 for example, is shown schematically in Fig. 2. It will be appreciated that, for purposes of simplicity, the differing angles of inclination among the orbits are not indicated in Fig. 2, wherein the orbits are shown in a North Pole plan view of a generally spherical body 36, which may be earth. A generally circular orbit 38 lies relatively close to the surface of the 35 body 36, and serves as the LEO. A generally circular orbit 40 of larger radius is the GEO. Velocity changes are indicated schematically on the drawing to represent the various engine

burns required to transfer from one orbit to another. The velocity changes may alter the angles of inclination of the orbits as well as their sizes and shapes as needed. For example, the tanker orbit transfer vehicle with equal fuel capacity in the two stages leaves LEO 38 with the first stage engine burn effecting a velocity change of ΔV_1 to establish the linked stages in a generally elliptical parking orbit 42 whose perigee is generally equal to the radius of LEO 38.

The connector assembly 16 is operated to free the second stage from the first, and the second stage engine assembly 28 is operated to achieve the change in velocity ΔV_2 that carries the second stage 14 into a generally elliptical transfer orbit 44 whose perigee is approximately equal to the radius of LEO 38 and whose apogee is approximately equal to the radius of GEO 40.

It will be appreciated that the second stage burn to achieve ΔV_2 is timed to take place when the disassociated second stage 14 is passing through the perigee of the parking orbit 42 so that both elliptical orbits have the same perigee at the same location. At the apogee of the transfer orbit 44, the second stage engine assembly 28 is again burned to effect the change in velocity ΔV_3 to carry the second stage into GEO.

After completion of mission activities in GEO, the second stage engine assembly 28 is activated to effect the decrease in velocity ΔV_4 that places the second stage back in the transfer orbit 44, or another transfer orbit of similar size and shape whose apogee is coincidental with the radius of GEO 40 and whose perigee is tangent to the parking orbit 42. Thereafter, the second stage engine assembly is again activated to produce the further lessening of velocity of the second stage ΔV_5 when the second stage is at perigee of the transfer orbit to place the second stage in the parking orbit 42. The two stages rendezvous in the parking orbit 42, after which the first stage engine assembly 22 is operated to produce the decrease in velocity ΔV_6 for the combined first and second stages to return the tanker orbit transfer vehicle 10 to LEO 38 for pickup by a shuttle or other such rendezvous as required. For ease of rendezvous operations, the return transfer orbit should be as nearly identical to the first transfer orbit 44, allowing the second

stage 14 to enter LEO at the perigee of the parking orbit 42 where the first stage 12 may be located.

Variation of the fuel capacity of each of the two stages, that is, variation also of the sizes of the two stages including their respective masses, results in modifications in the shapes and sizes of the intermediate parking and transfer orbits. In particular, in the tanker orbit transfer vehicle version utilizing an engine assembly on the second stage only, the second stage utilizes fuel stored in the first stage during burns out 5 of and back to LEO, while the first stage serves only as a tanker storage facility. Consequently, the first stage may be several times larger than the second stage for increased fuel use efficiency, resulting in an orbit pattern as schematically represented in Fig. 3, for example. In such a configuration, 10 the second stage engine burns fuel transferred along the fuel transfer line 34 (Fig. 1) from an oversized first stage 12 to effect a velocity increase $\Delta V_1'$ to remove the tanker orbit transfer vehicle from LEO 38 about the body 36 to an extended 15 elliptical parking orbit 46. The second stage 14 is then separated from the first stage, which remains in the parking orbit 46, while the second stage engine assembly is operated to effect a velocity increase $\Delta V_2'$ at perigee of the parking orbit to place the second stage in a transfer orbit 48 whose apogee is coincidental with the radius of GEO 40. There, at the 20 transfer orbit 48 apogee, the second stage engine is again operated to effect the velocity increase $\Delta V_3'$ to establish the 25 second stage in GEO 40.

At the completion of operations in GEO, the second stage engine assembly is again operated to slow the second stage by 30 the velocity change $\Delta V_4'$ to place the second stage in a transfer orbit, which may be the orbit 48 (as discussed above), whose perigee is coincidental with the parking orbit perigee 46. At such perigee point, the second stage engine is again burned to slow the second stage by the velocity difference $\Delta V_5'$ 35 to return the second stage to the parking orbit 46, wherein it docks with the first stage and recoupling of the fuel transfer line 34 can be effected. The second stage utilizes fuel from the first stage to operate the second stage assembly again to

slow the tanker orbit transfer vehicle by the velocity difference $\Delta V_6'$ to return the vehicle to LEO 38.

An aero-tanker, or tanker orbit transfer vehicle including an aero-brake, is illustrated at 50 in Fig. 4. This version of the tanker orbit transfer vehicle may again be constructed of modified Centaur rockets as illustrated. For example, the first stage 52 includes a stretched Centaur rocket for increased fuel capacity, while the second stage 54 may be constructed from a shortened Centaur rocket, yielding a large capacity differential in favor of the first stage for maximum efficiency of the craft. The two stages are joined by a connector assembly 56 designed to separate along the plane indicated by the arrow 58. The first stage 52 includes the enlarged propellant fuel container 60 and a first stage engine assembly 62. The second stage 54 includes the relatively diminished propellant fuel container 64 and the second stage engine assembly 66. The payload capsule 68 completes the major portions of the second stage 54.

An aero-brake 70 is shown deployed on a support system 72 at the back end of the first stage 52. The aero-brake 70 comprises a heat shield of extended cross section to provide significant drag as the aero tanker passes through the upper atmosphere to effect a speed decrease. The aero-brake 70 may be collapsible for transport to LEO from the earth's surface within a shuttle, for example, and/or the aero-brake may be assembled on the first stage 52 in space while the aero-tanker is in LEO. The aero-brake may be reusable, or it may be expendable.

To fly the aero-tanker 50, the craft is returned to the upper atmosphere where the aero-brake 70 interacts with the atmosphere to provide wind resistance, thus lessening the speed of the craft. The aero-tanker 50 may proceed through the atmosphere to return to LEO. While flying in the atmosphere under influence of the aero-brake 70, the aero-tanker 50 may be guided and generally controlled by selected manipulation of the attitude of the craft and/or selected operation of one or more of its engine assemblies.

Fig. 5 illustrates schematically an orbit pattern which

may be followed by an aero-tanker such as that illustrated in Fig. 4. In this configuration, the first stage engine assembly 62 is burned to achieve a major velocity change ΔV_1 " to place the craft in an intermediate transfer orbit 74, whose apogee may
5 be coincidental with the radius of the GEO 40 to be achieved. Thereafter, at apogee, the first stage engine assembly 62 is again burned to achieve a second velocity change ΔV_2 " to enlarge the elliptical orbit of the craft to a parking orbit 76. From the parking orbit 76, the second stage 54, now dis-
10 associated from the first stage 52 by separation of the connector assembly 56, is placed into GEO 40 by a burn of the first stage engine assembly 66 to achieve another velocity increase ΔV_3 ". Upon completion of the mission in GEO 40, the secnd stage 54 is returned to the parking orbit 76 by operation
15 of the second stage engine assembly 66 to decrease the speed of the second stage by ΔV_4 ". The first and second stages 52 and 54, respectively, rendezvous in the parking orbit 76, and reconnect the assembly 56. Thereafter, at apogee of the parking orbit 76, the first stage engine assembly 62 is fired to achieve
20 an additional slowing of the spacecraft by an amount ΔV_5 " to place the aero-tanker back into a transfer orbit, such as 74. The aero-brake 70 operates to further slow the aero-tanker by an amount ΔV_6 "upon passage of the aero-tanker within the outer atmosphere of the body 36 at perigee to return the craft to LEO
25 38. It will be appreciated that, since the second stage 54 of the aero-tanker 50 need carry only sufficient fuel to achieve the velocity changes ΔV_3 " and ΔV_4 " to place the second stage into GEO and to remove the second stage therefrom, the first stage 52 may be several times larger than the second stage to
30 maximize the efficiency of fuel transport throughout the mission.

As noted above, there are several types of missions that may be carried out using a tanker orbit transfer vehicle according to the present invention. Perhaps the most common such mission would be the delivery of a payload to GEO, where the payload is left, such as in the case of one or more satellites being placed in orbit. Perhaps the next most common mission would be a manned mission in which a payload comprising

the crew is brought to GEO and returned to LEO after the crew repairs or otherwise services satellites in GEO. Another type of planned mission would be a retrieval mission, in which a payload is picked up in GEO and returned to LEO as in the case 5 of the retrieval of a failed satellite, for example.

A contingency rescue mission may be carried out in a situation where, for example, the second stage is stranded in GEO with an inoperable engine, if the first stage is also equipped with an engine assembly. In such a situation, the 10 first stage engine assembly may be operated to increase the velocity of the first stage to take the first stage from the parking orbit into an elliptical transfer orbit, such as 44 in Fig. 2, for example. At apogee of such a transfer orbit, the first stage engine assembly is again operated to place the first 15 stage in GEO, where it may rendezvous and dock with the stranded second stage. Fuel may then be transferred from the second stage to the first stage, which returns to LEO by use of the first stage engine assembly. With sufficient fuel capacity, the second stage may be linked to the first stage during the 20 return trip, or the crew from the second stage, if any, may transfer to the first stage in GEO and return without the second stage, arriving in the first stage in space suits, for example.

It will be appreciated that the intermediate elliptical orbits are subject to shifting relative to the GEO with time due 25 to perturbation effects. Such perturbation effects can pose a factor to be considered when a substantial time passes between the separation of the first and second stages in the parking orbit and return of the second stage to GEO for rendezvous with the first stage. For example, if the second stage is placed in 30 geosynchronous orbit in GEO, generally there will be one opportunity per day for return of the second stage to the parking orbit and rendezvous and docking with the first stage with minimum use of the engine assemblies for maneuvering the two stages into contact. Because of the perturbation effects, 35 the change in velocity to place the second stage in a proper transfer orbit for return from GEO to rendezvous with the first stage, and the change in velocity to achieve the parking orbit for rendezvous, increases with time.

Fig. 6 is an illustration of the shifting of the elliptical orbits coincidental with a one week mission in GEO for a tanker orbit transfer vehicle wherein the two stages are of equal fuel capacity, such as the case for which orbits are schematically represented in Fig. 2 for example. In Fig. 6, the line of nodes 78 represents the intersection of the plane of the parking orbit 80, and the plane of the transfer orbit 82 (in their original orientations as illustrated in Fig. 2) with the plane of GEO 40, that is, the equatorial plane. Such is the case, for example, where no plane shift is effected between the parking orbit and the transfer orbit. It may be determined that the line of nodes shifts 1.6 degrees per day due to perturbation effects about earth. The resulting shift in the line of nodes is indicated by the angle A, and the greater shift in the parking orbit orientation is indicated by the angle B. As indicated in Fig. 6, a change in velocity of $\Delta V'$ must be experienced by the second stage to transfer from GEO into a transfer orbit 82, as opposed to the velocity change ΔV_4 indicated in Fig. 2; similarly, to rendezvous with the first stage in the reoriented parking orbit 80, the second stage must undergo a change in velocity of $\Delta V''$ compared to ΔV_5 of Fig. 2.

It will be appreciated, particularly by reference to the various orbit schemes illustrated herein, such as that of Fig. 2, for example, that a completed round trip from LEO to GEO and back to LEO by a tanker orbit transfer vehicle as described herein may be carried out with minimum fuel consumption when the time between the departure of the second stage from the parking orbit and its return thereto for the rendezvous with the first stage is minimized. Further, the return transfer orbit from GEO to the parking orbit should be as nearly as possible identical with the elliptical orbit defined in the initial instance of transit from the parking orbit to GEO by the second stage, allowing for perturbation effects as discussed hereinbefore. To minimize such perturbation effects, the second stage should leave GEO at the first opportunity after arrival, which should occur approximately 24 hours later. Further, fuel consumption may be minimized by timing the arrival of the second stage at the perigee of the return transfer orbit to coincide with the

arrival at that location of the first stage, the perigees of the return transfer orbit and that of the parking orbit preferably being as close together as possible.

As noted hereinbefore, the first, or tanker, stage is intended to carry all of the fuel to be consumed while the first and second stages are connected, for example in travel between LEO and a parking orbit. However, exceptions to such a program would include a situation in which the first stage is used in a rescue mission to GEO, as described above, for example. Other such exceptional circumstances may occur.

While plane inclination changes may be effected whenever one or both stages of the tanker orbit transfer vehicle according to the present invention undergoes an orbit alteration, for purposes of ease of manipulation of the craft and particularly for facilitating rendezvous and docking, it is anticipated that the major portion of the plane inclination change between LEO and GEO would be effected between the transfer orbit and GEO, with some plane inclination change occurring between LEO and the parking orbit, while little or no plane inclination change is anticipated between the parking orbit and the transfer orbit(s).

The efficiency of a tanker orbit transfer vehicle according to the present invention compared to earlier proposals for orbit transfer vehicles may be measured, at least in part, by the amount of payload that may be transported between LEO and GEO by the various craft. All of the versions of the tanker orbit transfer vehicle described and illustrated herein may be shown to be capable of carrying greater payloads between LEO and GEO than any of the earlier proposed orbit transfer vehicles discussed above. Further, the tanker orbit transfer orbit vehicle with enlarged first stage compared to the second stage, and including an engine assembly on the second stage only, is capable of transporting greater payloads than the version of the tanker orbit transfer vehicle having two like stages, of equal fuel capacity and equipped with engine assemblies. Additionally, the aero-tanker is capable of negotiating an even greater payload than the tanker orbit transfer vehicle version with but one engine assembly and enlarged first stage.

It will be appreciated that the present invention provides a tanker orbit transfer vehicle which is entirely reusable, and capable of carrying larger payloads between concentric orbits than any earlier proposed orbit transfer vehicles, and is
5 therefore generally more economical to use.

The foregoing disclosure and description of the invention is illustrative and explanatory thereof, and various changes in the method steps as well as in the details of the illustrated apparatus may be made within the scope of the appended claims
10 without departing from the spirit of the invention.

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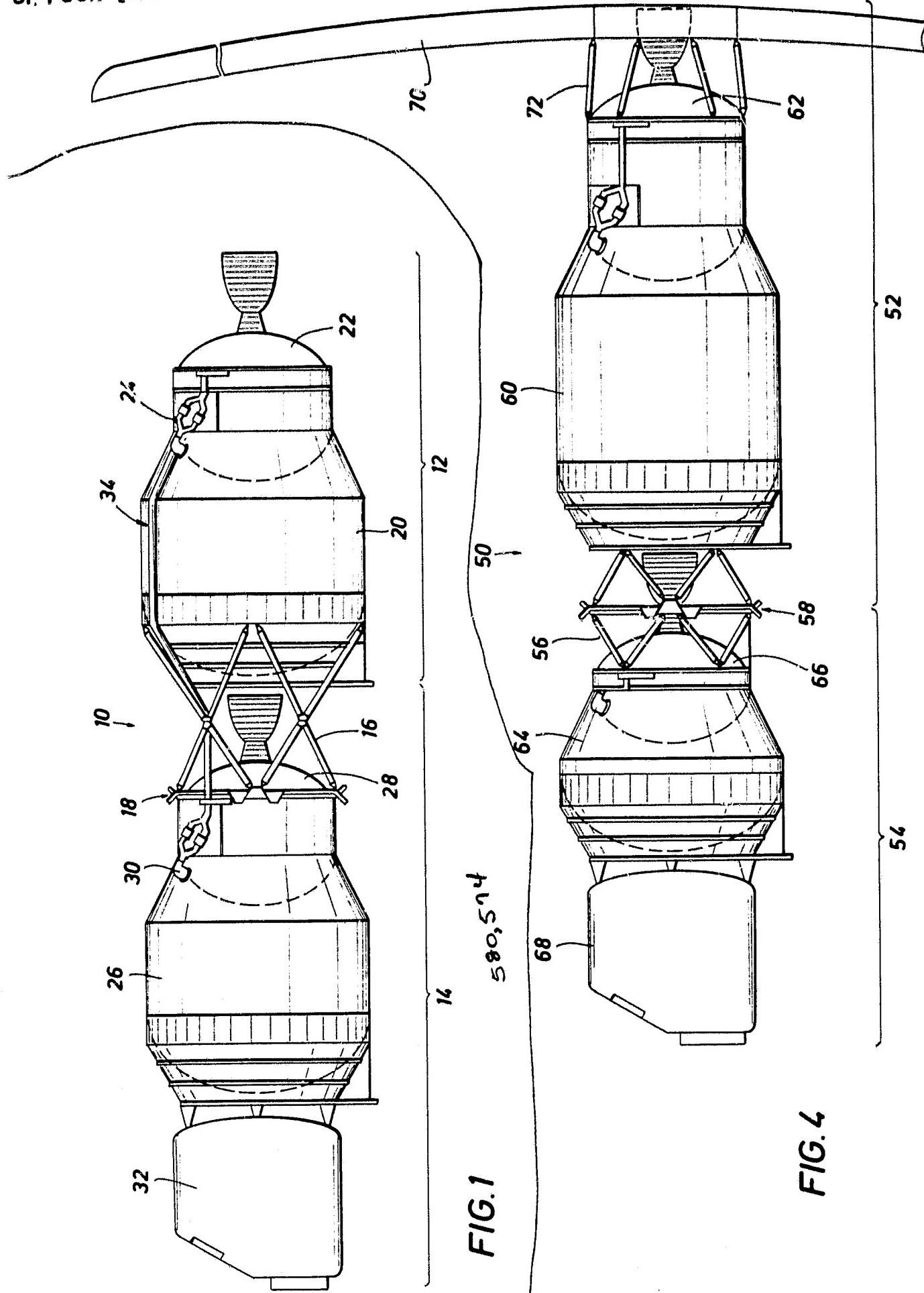


FIG. 1

FIG. 4

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OF POOR QUALITY

FIG. 2

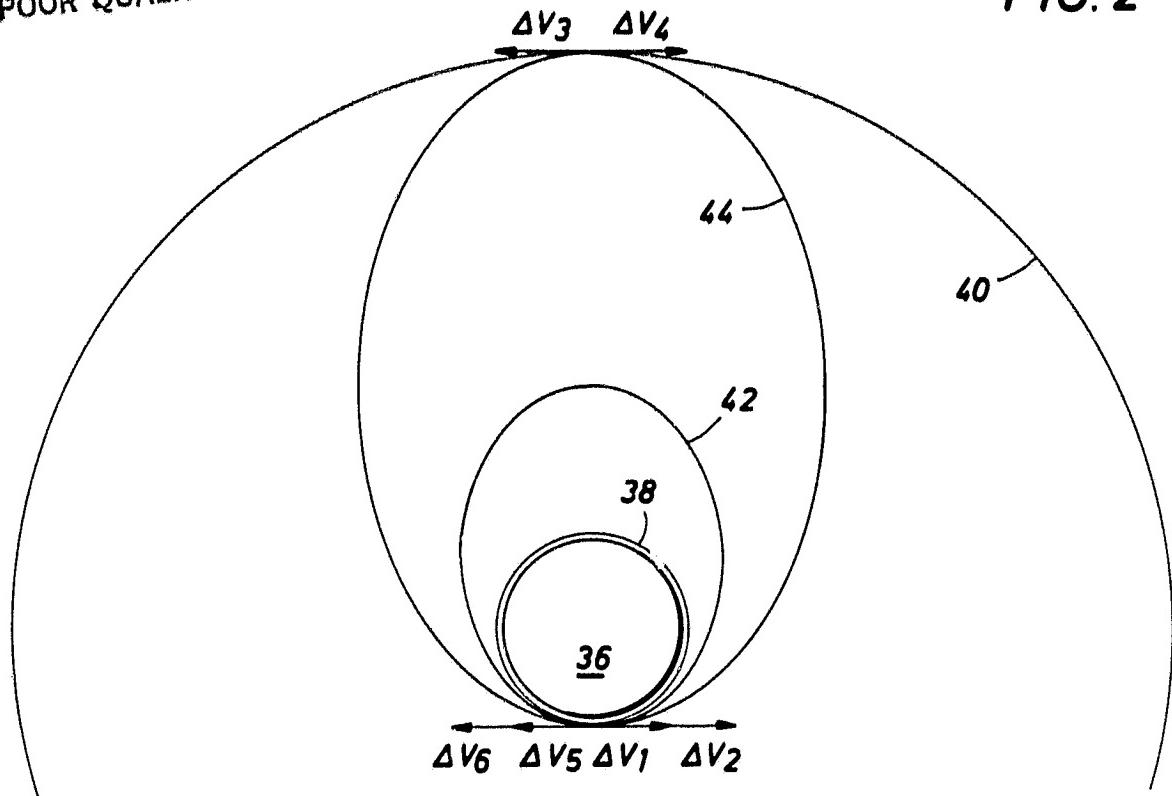


FIG. 3

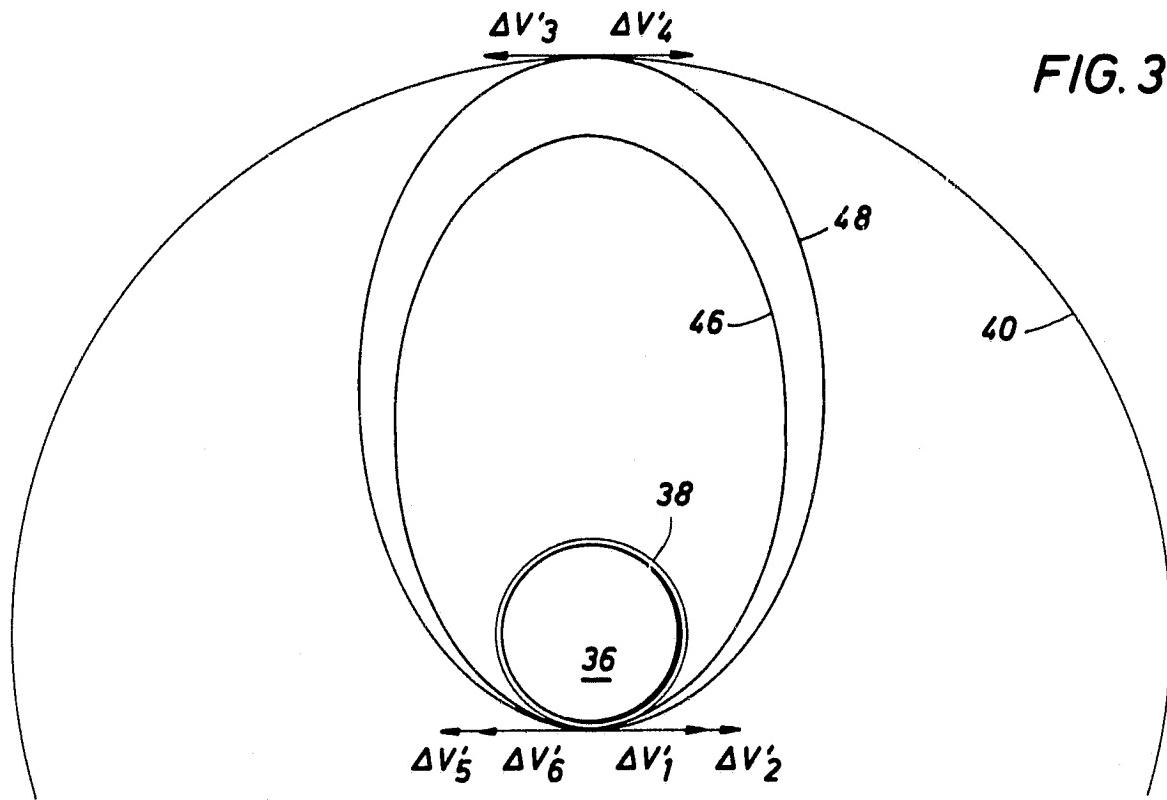


FIG. 5

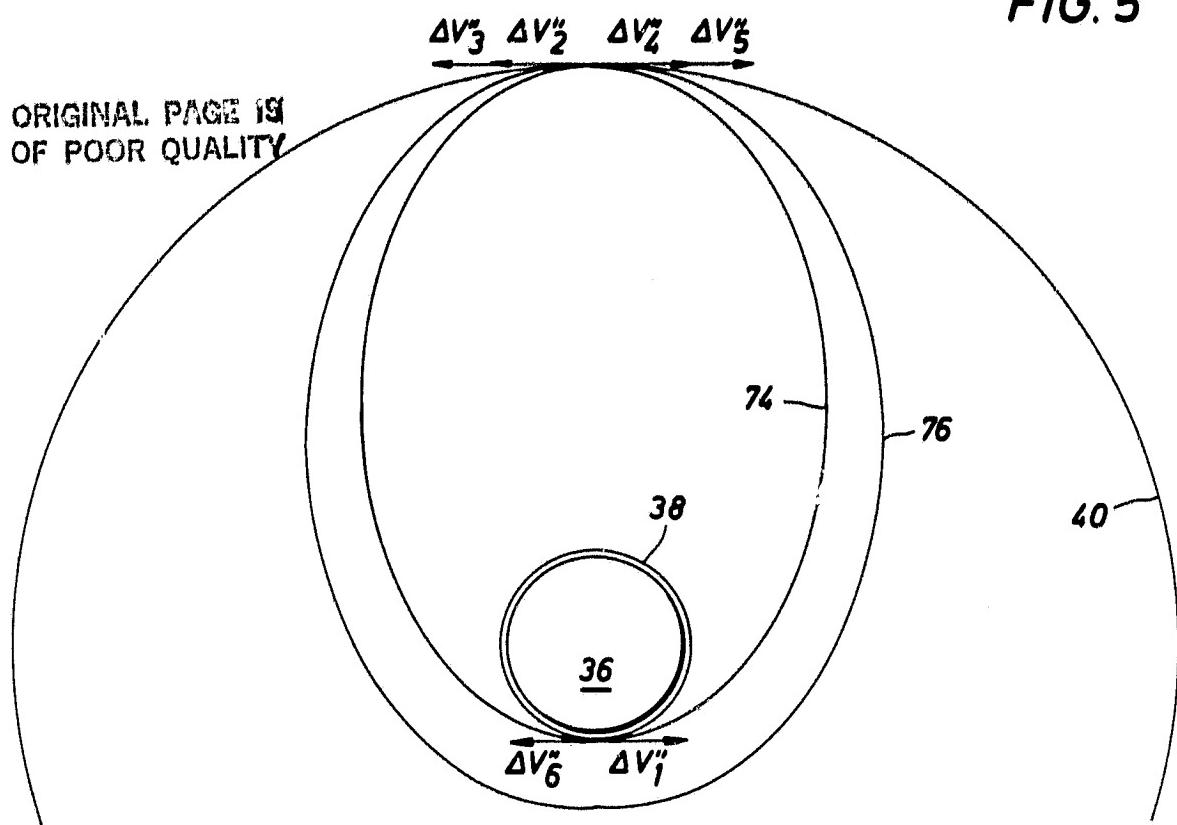
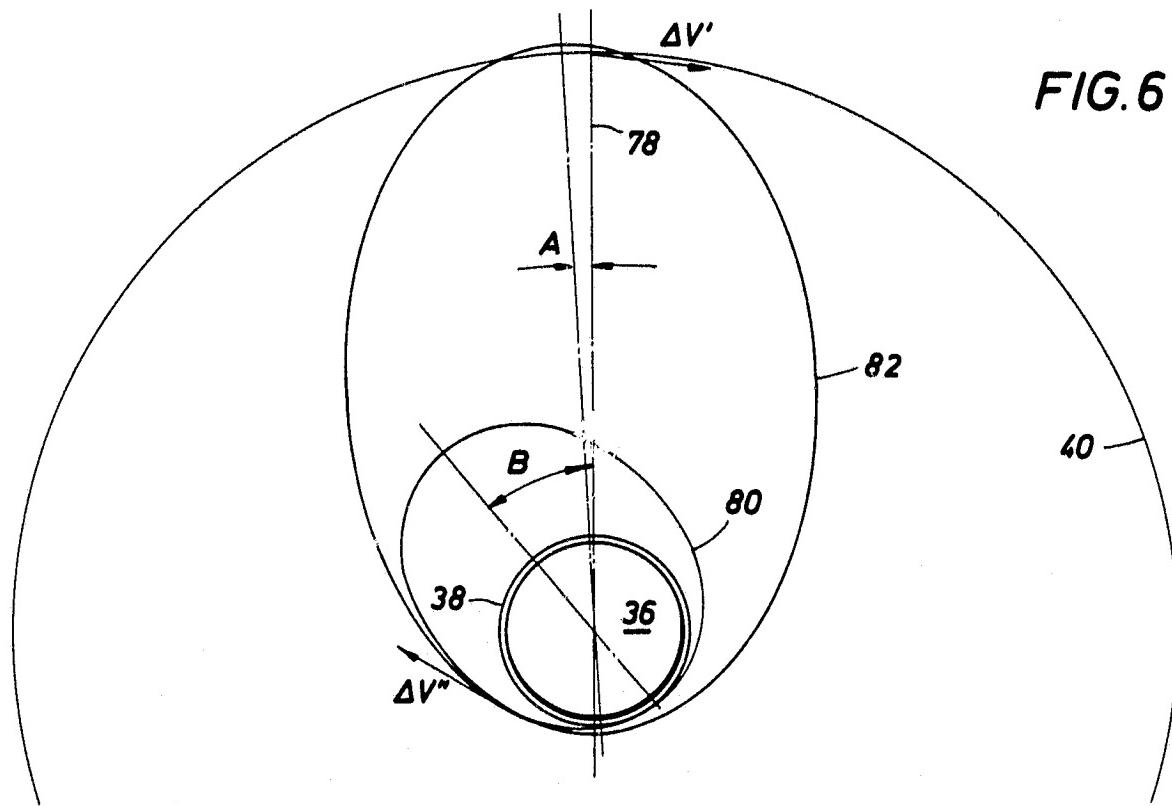


FIG. 6



TANKER ORBIT TRANSFER VEHICLE AND METHOD

Abstract of the Disclosure

Disclosed are method and apparatus for transportation between orbits, about earth for example. A tanker orbit transfer vehicle includes two stages, each including a fuel container. The first stage may be left in an intermediate parking orbit while the second stage goes on to carry out a mission, thereafter to return to rendezvous and dock with the first stage. Fuel carried by the first stage may be utilized for travel of the two stages between the starting orbit and the parking orbit, and for return to the starting orbit. An aero-brake may be included in the system for use in the return to the initial orbit.